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# Zonal variations in abundance and body length of chaetognaths in the 140°E seasonal ice zone during the austral summer of 2001/02

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## Abstract

Time-series observations of chaetognaths were carried out during four cruises along the 140°E transect between 61°S and 66°28′S from November to March in the 2001/02 austral summer. Three species – *Eukrohnia hamata*, *Sagitta gazellae* and *Sagitta marri* – occurred in the samples between 0 and 150 m. *E. hamata* was the most dominant species comprising between 89.6 and 100% of the chaetognath population, followed by *S. gazellae* (0–5.7%). There were large differences in the abundance and size frequency distribution of body length of *E. hamata* between the north and south of the Southern Boundary of the Antarctic Circumpolar Current (SB-ACC) which was located between 64°S and 65°S. For *E. hamata*, low abundance and large sized animals (22–24 mm) occurred south of the SB-ACC. A possible reason could be that the breeding season in waters north of the SB-ACC may be early spring and summer. On the other hand, low reproduction was recognized by low the abundance of *E. hamata* and few occurrences of juveniles south of the SB-ACC (65°S). The result of a general comparison suggests that the abundance of chaetognaths along the 140°E transect has decreased during the 20 years since 1983.


*Keywords:* *Eukrohnia hamata*; Southern boundary; Multi-ship survey

## 1. Introduction

Chaetognatha are major zooplankton predators in the Southern Ocean (Hopkins, 1971; Terazaki, 1989; Froneman et al., 1998). Among all zooplankton groups, they are second in abundance following Copepoda and their predation can place heavy pressure on copepod communities (Øresland, 1990; Froneman and Pakhomov, 1998; Froneman et al., 2002). The chaetognath fauna of the Southern Ocean is made up of nine species: *Eukrohnia hamata*, *Eukrohnia bathypelagica*, *Eukrohnia fowleri*, *Eukrohnia bathyantarctica*, *Sagitta gazellae*, *Sagitta marri*, *Sagitta maxima*, *Sagitta macrocephala*, and *Heterokrohnia mirabilis* (David, 1965; Alvariño et al., 1983). Two dominant chaetognath species, *E. hamata* and *S. gazellae*, display ontogenetic migration, characterized by sexually mature adults spawning at deeper layers, followed by upward migration of juveniles during development, and then a return to deeper layers as they begin to mature (Sameoto, 1987; Øresland, 1990, 1995). However, the length of the life span and the breeding periods are unknown or uncertain for all

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chaetognath species in the Southern Ocean due to lack of information on size and maturity status through the whole year. A major cause of these uncertainties is the difficulty in obtaining seasonal coverage from the Southern Ocean.

There have been a number of previous studies reporting on the distribution of chaetognaths in the Antarctic and adjacent regions (Mackintosh, 1964; David, 1958, 1965; Alvariño, 1965; Alvariño et al., 1983; Terazaki, 1989; Johnson and Terazaki, 2004; Kruse et al., 2009; Giesecke and González, 2012). The basic pattern of their distribution is circumpolar, and some species of this group have been used as biological indicators of hydrographical conditions because of the recognized strong connection between water masses in the Southern Ocean (Mackintosh, 1964; David, 1965; Alvariño, 1965; Alvariño et al., 1983; Terazaki, 1989; Duró et al., 1999; Pakhomov et al., 2000; Jonson and Terazaki, 2004; Giesecke and González, 2012). The Southern Boundary of the Antarctic Circumpolar Current (SB-ACC) separates two flows; the comparatively warmer, eastward flowing ACC in the north and the colder westward flowing Coastal Current (CC) to the south. The SB-ACC is associated with the steepest physical gradients in the seasonal ice zone, and the distributions of some zooplankton species are strongly correlated with this front (Schnack-Schiel et al., 1995; Atkinson and Sinclair, 2000; Jonson and Terazaki, 2004; Hunt and Hosie, 2006; Tanimura et al., 2008). However, to our knowledge few studies have investigated the seasonal cycle of chaetognaths in this region.

Because the Japanese ship-based ocean surveys are usually conducted during the logistics voyage to the Syowa Base, few intra-annual seasonal studies have been undertaken. As a part of the Japanese Antarctic Research Expedition (JARE), time series plankton observations were carried out along a transect on the 140°E seasonal ice zone between 61°S and 66.28°S from November to March in the 2001/02 austral summer using four ships (Odate and Fukuchi, 2003). The objective of this study was to describe the zonal changes in horizontal abundance of chaetognaths and body length of the most dominant species, *E. hamata*, during the four months.

## 2. Materials and methods

Plankton samples were collected in the region of the Southern Ocean below Australia during the RSV *Aurora Australis* Voyage 3 (V3) Cruise of the Australian Antarctic program in November 2001; the R/V *Hakuho Maru* Cruise KH01-3 of the Ocean Research Institute of University of Tokyo in January 2002; the 43rd Japanese Antarctic Research Expedition (JARE-43) Marine Science Cruise of the RV *Tangaroa* in February 2002; and the Japanese ice-breaker *Shirase* in March 2002. Zooplankton sampling was carried out along a transect on 140°E between 61°S and 66°28′S (Fig. 1), which crossed different hydrological regimes north and south of the SB-ACC. The SB-ACC was defined by the southern limit of $\theta_{max}$ water warmer than 1.5 °C (Sokolov and Rintoul, 2002). The SB-ACC was closely spaced in the study area between 64°S and 65°S during the study periods (Aoki et al., 2006, Fig. 1).

A NORPAC standard net (0.45 m mouth diameter, 330 μm mesh size) was towed vertically from an approximate depth of 150 m, at a speed of *ca*. 1 m/s. The volumes of water filtered through each net were estimated from a flow-meter, which was mounted at the center of the mouth ring of each net. Further sampling information is shown in Table 1. Immediately after collection, all samples from each haul were preserved in 5% buffered formalin sea water. The number of chaetognaths for each species in each sample was counted. The body length (front of the head to the end of the tail, excluding fin) of *Eukrohnia hamata*, which was predominant in this sampling area, was measured using samples collected by the four ships at three fixed station (61°S, 64°S, and 65°S).

Data on surface temperature, salinity and chlorophyll *a* concentration were cited from the unpublished data file from Cruise V3, and published preliminary reports from Cruises KH-01–3 (Terazaki et al., 2003), JARE-43 *Tangaroa* (Odate, 2002) and JARE-43 *Shirase* (Kinoshita and Nosaka, 2005). Data for sea-ice concentrations were received from the National Snow and Ice Data Center (Comiso, 1990; updated 2003), and the position of the ice edge around 140°E was obtained courtesy of the National Ice Center. To review the relationships between surface primary production (mg C $m^{-3}$ $d^{-1}$), and abundance of copepods and chaetognaths (0–150 m) at 60–61°S and 65°S, data from SIBEX-1 Investigations in 1983/84 (Ocean Research Institute, 1985; Hosaka and Nemoto, 1986), R/V *Hakuho Maru* KH-94-4 Cruise in 1994/95 (Ocean Research Institute, 1996; Suzuki and Handa, 1996) and the present survey (Sasano and Hama, 2003) were compared.

## 3. Results

### 3.1. Sea-ice condition

The average maximum ice extent along 140°E was located at 62°30′S in October. In early November, the

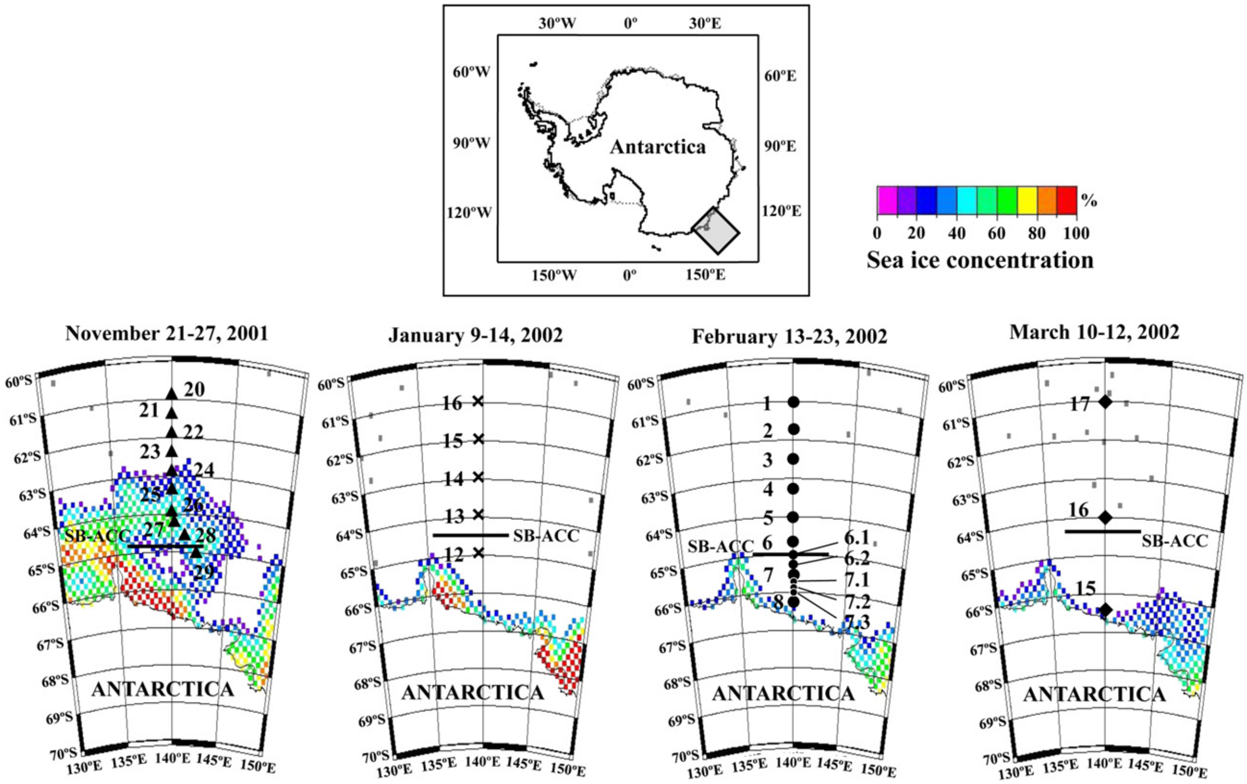


Fig. 1. Locations of zooplankton sampling stations and sea ice concentration during the 2001/02 multi-ship cruises. Lines indicate the approximate locations of the southern boundary of the Antarctic circumpolar current (SB-ACC) from Aoki et al. (2006).

sea ice edge was located between 62°S and 63°S, and then the ice edge had retreated to approximately 63°30′S at the time of sampling. The sampling sites in November 2001 therefore encompassed contrasting environments; pack-ice, ice-edge and ice-free open ocean. Stations 26 (63°55′S) to 29 (65°35′S) were covered by heavy pack-ice; Station 25 (63°22′S) was located in the ice-edge; Station 24 (62°51′S) was located in the drift-ice; and Stations 20 (60°51′S) to 23 (62°21′S) were located in open water (Fig. 1). In contrast, all sampling stations from January to March were located in open water (Fig. 1).

### 3.2. Hydrography

In November, the sea-ice distribution corresponded with the sea surface temperature values <−1.5 °C south of 63°S (Table 1). Salinity increased rapidly south of the SB-ACC (*ca*. 64°30′S) as determined from vertical profiles by Aoki et al. (2006). The retreat of the ice-edge coincided with the summer warming of surface waters (0.75–1.42 °C in January; Table 1). In February and March, sea surface temperature cooled rapidly south of the SB-ACC, and a rapid increase in surface salinity was observed south of the same latitude range (Table 1).

Surface chlorophyll *a* concentration was <0.56 μg $l^{-1}$ throughout the survey area in November (Table 1). The highest chlorophyll *a* concentration occurred south of the SB-ACC between January to March. In January, a phytoplankton bloom with 9.93 μg $l^{-1}$ chlorophyll *a* concentration was observed at 65°S. Chlorophyll *a* remained relatively high south of the SB-ACC in February (4.70 μg $l^{-1}$), however, by March it had decreased to <1.90 μg $l^{-1}$ (Table 1).

### 3.3. Chaetognath abundance and body length

*Eukrohnia hamata* was the most dominant species at all stations, comprising 89.6–100% of the chaetognath community. High abundance of more than 3.9 inds. $m^{-3}$ was recorded at Station 23 (62°21′S) and 28 (64°30′S) in November (Fig. 2). In January, the abundance of *E. hamata* decreased going southward and maximum abundance (7.3 inds. $m^{-3}$) was observed at Station 16 (61°S). The abundance of *E. hamata* in February was high at stations between 62°S and 64°S, and decreased rapidly south of SB-ACC (Fig. 2). In March, the

Table 1
Sampling information for NORPAC net tows, surface temperature, salinity, chlorophyll *a* concentration and sea-ice concentration during 2001/02 multi-ship program and other cruises.

| Station number | Date | Location | | Sampling depth (m) | Temp. (°C) | Salinity | Chl *a* (μg $L^{-1}$) | Sea-ice conc. |
|---|---|---|---|---|---|---|---|---|
| | | Lat. (S) | Long. (E) | | | | | |
| November 2001 (*Aurora Australis*) | | | | | | | | |
| 20 | Nov. 21 | 60° 51.0′ | 139° 51.0′ | 0–150 | −0.05 | 33.91 | 0.36 | 0 |
| 21 | Nov. 22 | 61° 21.0′ | 139° 51.0′ | 0–150 | −0.43 | 33.89 | 0.41 | 0 |
| 22 | Nov. 23 | 61° 51.0′ | 139° 51.0′ | 0–150 | −1.14 | 33.79 | 0.56 | 0 |
| 23 | Nov. 23 | 62° 21.0′ | 139° 51.0′ | 0–150 | −1.43 | 33.77 | 0.38 | 0 |
| 24 | Nov. 24 | 62° 51.0′ | 139° 51.0′ | 0–150 | −1.35 | 33.68 | 0.46 | 28.7 |
| 25 | Nov. 25 | 63° 22.0′ | 139° 51.0′ | 0–150 | −1.60 | 33.86 | 0.44 | 35.0 |
| 26 | Nov. 25 | 63° 55.0′ | 139° 51.0′ | 0–150 | −1.59 | 33.81 | 0.33 | 50.3 |
| 27 | Nov. 26 | 64° 10.0′ | 140° 25.0′ | 0–150 | −1.60 | 33.85 | 0.35 | 54.7 |
| 28 | Nov. 27 | 64° 30.7′ | 141° 20.6′ | 0–150 | −1.65 | 33.89 | 0.54 | 45.7 |
| 29 | Nov. 27 | 65° 03.0′ | 142° 32.0′ | 0–150 | −1.66 | 34.07 | 0.30 | 15.8 |
| January 2002 (*Hakuho Maru*) | | | | | | | | |
| 16 | Jan. 15 | 61° 00.0′ | 140° 00.0′ | 0–150 | 1.15 | 33.88 | 1.06 | 0 |
| 15 | Jan. 14 | 62° 00.0′ | 140° 00.0′ | 0–150 | 1.42 | 33.81 | 1.25 | 0 |
| 14 | Jan. 13 | 63° 00.0′ | 140° 00.0′ | 0–150 | 1.38 | 33.54 | 0.97 | 0 |
| 13 | Jan. 12 | 64° 00.0′ | 140° 00.0′ | 0–150 | 0.75 | 33.60 | 2.17 | 0 |
| 12 | Jan. 9 | 65° 00.0′ | 140° 00.0′ | 0–150 | 0.88 | 33.77 | 9.93 | 0 |
| February 2002 (*Tangaroa*) | | | | | | | | |
| 1 | Feb. 23 | 61° 00.0′ | 140° 00.0′ | 0–150 | 1.86 | 33.79 | 0.15 | 0 |
| 2 | Feb. 22 | 61° 45.0′ | 140° 00.0′ | 0–150 | 1.67 | 33.73 | 0.21 | 0 |
| 3 | Feb. 21 | 62° 30.0′ | 140° 00.0′ | 0–150 | 1.38 | 33.69 | 0.23 | 0 |
| 4 | Feb. 20 | 63° 15.0′ | 140° 00.0′ | 0–150 | 1.26 | 33.66 | 0.31 | 0 |
| 5 | Feb. 15 | 64° 00.0′ | 140° 00.0′ | 0–150 | 1.16 | 33.71 | 0.38 | 0 |
| 6 | Feb. 19 | 64° 45.0′ | 140° 00.0′ | 0–150 | −0.11 | 33.80 | 0.95 | 0 |
| 6.1 | Feb. 19 | 65° 00.0′ | 140° 00.0′ | 0–150 | −0.60 | 34.04 | – | 0 |
| 6.2 | Feb. 18 | 65° 15.0′ | 140° 00.0′ | 0–150 | −0.71 | 33.96 | – | 0 |
| 7 | Feb. 18 | 65° 30.0′ | 140° 00.0′ | 0–150 | −0.92 | 34.09 | 1.24 | 0 |
| 7.1 | Feb. 18 | 65° 35.0′ | 140° 00.0′ | 0–150 | −0.99 | 34.10 | – | 0 |
| 7.2 | Feb. 18 | 65° 45.0′ | 140° 00.0′ | 0–150 | −0.97 | 34.10 | – | 0 |
| 7.3 | Feb. 18 | 66° 00.0′ | 140° 00.0′ | 0–150 | −0.90 | 34.10 | – | 0 |
| 8 | Feb. 13 | 66° 15.0′ | 140° 00.0′ | 0–150 | −0.70 | 34.23 | 4.70 | 0 |
| March 2002 (*Shirase*) | | | | | | | | |
| 17 | Mar. 12 | 61° 02.0′ | 139° 58.3′ | 0–150 | 1.98 | 33.80 | 0.05 | 0 |
| 16 | Mar. 11 | 63° 59.2′ | 140° 01.6′ | 0–150 | 1.01 | 33.67 | 0.13 | 0 |
| 15 | Mar. 10 | 66° 28.0′ | 140° 00.7′ | 0–150 | −1.36 | 34.39 | 1.90 | 0 |
| December 1983 (*Hakuho Maru*) | | | | | | | | |
| 3B | Dec. 25 | 61° 24.8′ | 150° 05.7′ | 0–200 | 0.19 | 33.97 | – | 0 |
| 4 | Dec. 22 | 64° 56.4′ | 150° 12.8′ | 0–200 | −0.47 | 33.85 | – | 0 |
| December 1994 (*Hakuho Maru*) | | | | | | | | |
| 23 | Dec. 29 | 61° 00.0′ | 140° 00.0′ | 0–150 | 1.46 | 33.85 | 0.11 | 0 |
| 14 | Dec. 26 | 65° 05.0′ | 140° 00.0′ | 0–150 | −1.08 | 33.73 | 0.39 | 0 |

abundance of *E. hamata* ranged from 0.08 to 2.42 inds. $m^{-3}$ (Fig. 2).

Very few of the smaller size classes were observed at 65°S, while smaller individuals less than 6 mm were abundant north of the SB-ACC except for February and March of 61°S (Fig. 3). Large sized animals (22–24 mm in body length) occurred at the southern station (65°S) in November (Fig. 3). In January, many juveniles (<6 mm) occurred at 61°S at a density of 429 inds. $m^{-3}$. However, the body length of *E. hamata* collected at one of the most southerly sites, Station 8 (66°15′S), ranged from 6 to 14 mm. In March, two individuals (5 mm and 10 mm in body length) were collected from the most southerly station (66°28′S).

*Sagitta gazellae* was collected from all stations in November but its abundance was lower than 0.14 inds. $m^{-3}$ (Fig. 4). In January and March, the species was collected at all stations except the southernmost stations. In February, *S. gazellae* was collected from 6

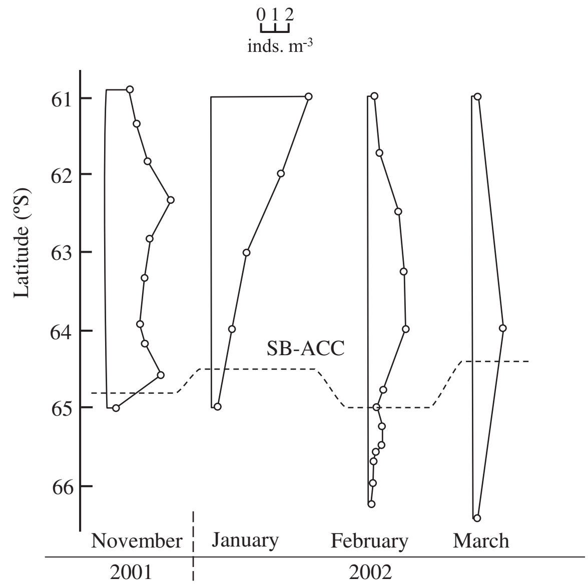


Fig. 2. Abundance of *Eukrohnia hamata* along a transect on 140°E in the seasonal ice zone of the southern ocean.

stations (61°45′S, 63°15′S, 64°S, 65°15′S, 65°35′S and 65°45′S) out of the total 13 stations (Fig. 4). Few numbers of *Sagitta marri* occurred at four stations (62°51′S, 63°22′S, 63°55′S and 65°03′S) in November, two stations (61°S and 65°S) in January and three stations (63°15′S, 64°S, and 65°15′S) in February. No *S. marri* were collected in March.

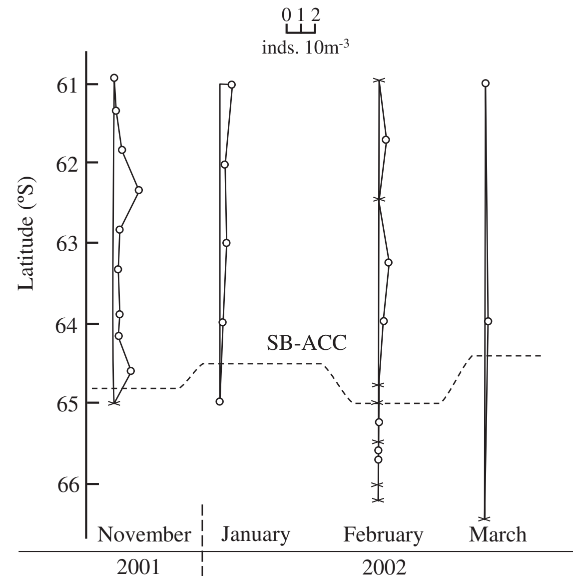


Fig. 4. Abundance of *Sagitta gazellae* along a transect on 140°E in the seasonal ice zone of the southern ocean. “X” mark represents no *S. gazellae* were collected.

### 3.4. Change of primary production and abundance of copepods and chaetognaths

Primary production at 65°S was higher than at 60–61°S in 1983 (Hosaka and Nemoto, 1986), 1994 (Suzuki and Handa, 1996), and 2002 (Sasano and Hama, 2003) (Table 2). The abundance of copepods

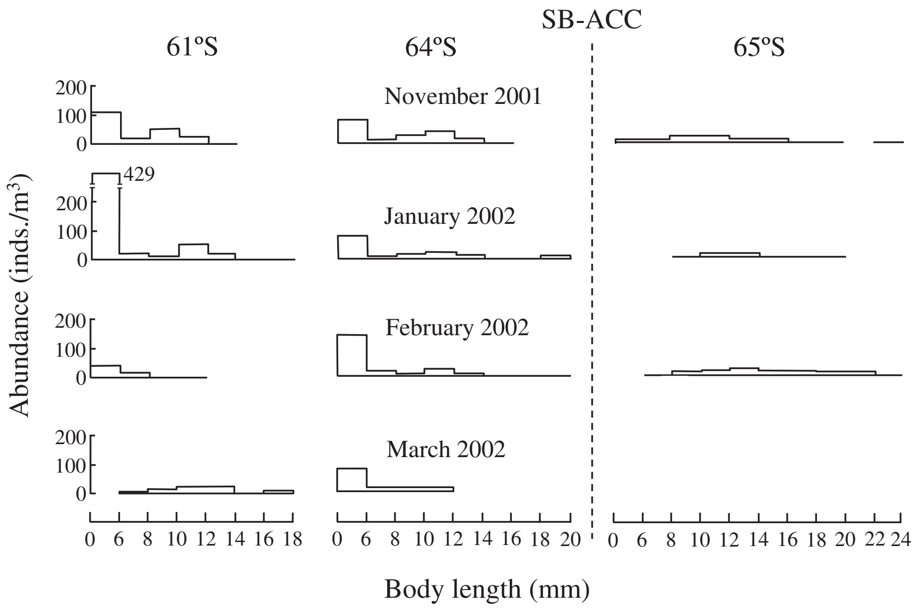


Fig. 3. Length-frequency distribution of *Eukrohnia hamata* at 61°S, 64°S and 65°S in the seasonal ice zone of the southern ocean.

Table 2
Abundance (inds. $m^{-3}$) of copepods and chaetognaths (0–150 m) and surface primary production (mg C $m^{-3}$ $d^{-1}$) in 60–61°S and 65°S. Primary production was measured by the simulated *in situ* methods using a 14C uptake (Dec. 1983) and a 13C-technique (Dec.1994 and Jan. 2002).

| Period | Position | Primary production | Copepods abundance | Chaetognaths abundance | Copepods/chaetognaths ratio |
|---|---|---|---|---|---|
| December 1983 | 60°S | 8.28[a] | 678.90 | 10.07 | 6.74 |
| | 65°S | 22.54[a] | 38.17 | 7.33 | 5.21 |
| December 1994 | 60°S | 6.80[b] | 103.97 | 2.42 | 42.96 |
| | 65°S | 9.00[b] | 11.13 | 0.75 | 14.84 |
| November 2001 | 60°S | No data | 8.52 | 1.86 | 4.58 |
| | 65°S | No data | 12.43 | 0.70 | 17.76 |
| January 2002 | 61°S | 2.60[c] | 134.31 | 7.48 | 17.96 |
| | 65°S | 23.50[c] | 12.17 | 0.35 | 34.77 |

[a] Hosaka and Nemoto (1986).
[b] Suzuki and Handa (1996).
[c] Sasano and Hama (2003).

and chaetognaths were highest at both stations in 1983. Usually, copepods and chaetognaths were more abundant at 60–61°S than at 65°S except in November 2001 (Table 2). The ratio of Copepods/Chaetognaths ranged from 5.21 to 42.96.

## 4. Discussion

The study area fell within a larger region (115–150°E) characterized by a seasonal ice zone much narrower than in other areas of Antarctica (Nicol et al., 2000). Therefore, the results of this study gave insight into the information of a region of low sea-ice extent. Chaetognaths occurred at all stations during the four months, and they were also recorded in the southern stations under heavy pack-ice conditions in November. Contrary to herbivorous and some omnivorous zooplankton, chaetognaths remain active and even reproduce during winter (Øresland, 1995). The present results have provided evidence of active behavior of chaetognaths under the sea-ice before the sea-ice dissipated.

### 4.1. Abundance and body length of Eukrohnia hamata

*Eukrohnia hamata* is an oceanic species extending along the meso- and bathypelagic layers in the tropical and equatorial regions, but rising to epiplanktonic levels or even the surface in the polar areas it inhabits (Alvariño, 1965). *E. hamata* was clearly the most dominant species in all months during the time series observations. This result concurs with several other studies in the Southern Ocean (Øresland, 1990, 1995; Froneman and Pakhomov, 1998; Froneman et al., 1998; Duró et al., 1999; Duró and Gili, 2001; Johnson and Terazaki, 2004). Low abundance of *E. hamata* were found south of the SB-ACC during the four months of the survey. Furthermore, large animals above 20 mm occurred in the most southern station (65°S) and were not collected from 61°S to 64°S during the four months. Thus, there is a large difference in the abundance and size frequency distribution of body length of *E. hamata* in the north and south of the SB-ACC. Smaller individuals of *E. hamata* in the Southern Ocean tend to be distributed in the upper 300 m depth, while larger individuals live below 500 m (Terazaki, 1989; Johnson and Terazaki, 2004). Hagen (1985) also found that this species occurred in the greatest abundance between 200 and 750 m depth. He concluded that differences in size and distribution of the developmental stages by depth were due to breeding migration of larger and more mature specimens into deep waters. However, this pattern tends to disappear in coastal regions (Øresland, 1990) and near the ice margin (Duró et al., 1999), as can be seen from our data in the south of the SB-ACC. Johnson and Terazaki (2004) suggested one possibility that mixing was the driving force in those distribution patterns, because the division of size classes ought to be more apparent in highly stratified regions (north of the SB-ACC).

Another factor may be the temporal variability in reproduction. Adults of *E. hamata* descend to deeper layers, at least between 500 and 1000 m, to reproduce, and when the eggs have hatched at those depths, the juveniles stay at those deeper levels for some time, later rising to the surface layers where they aggregate with adults (Sameoto, 1987; Øresland, 1990, 1995). There have been some reports on the breeding season of *E. hamata* in various waters. In Korsfjorden, Norway, *E. hamata* appeared to have a life span of two years with breeding at a maximum during spring and fall and at low level during summer (Sands, 1980).

Terazaki and Miller (1986) determined a life span of 8–10 months for *E. hamata* with three distinct breeding periods, early spring, summer, and autumn, in the northern Pacific. According to Øresland (1995), *E. hamata* near Antarctica may be engaged in breeding year round at a low rate continuously; however, the entire length of the life span is difficult to determine. In this study, many juveniles below 6 mm were collected from 61°S to 64°S in the 2001/02 summer but few juveniles occurred at 65°S. Therefore, the reproductive peak in the waters north of the SB-ACC might be early spring to summer. On the other hand, south of the SB-ACC at 65°S, the low abundance of *E. hamata* and low occurrence of juveniles indicated low reproduction.

### 4.2. Abundance of *Sagitta gazellae*

*Sagitta gazellae* was the second most dominant species during the time series observation, although it only comprised between 0 and 5.7% of the chaetognath population. Generally, *S. gazellae* is distributed in the shallow layer comparable to *E. hamata* (Terazaki, 1989; Johnson and Terazaki, 2004). They are distributed mainly in the 50–200 m layer in the Southern Ocean (David, 1965; Terazaki, 1989). Therefore, we have indeed collected the main bulk of the *S. gazellae* population. During our study, its abundance (<0.14 inds. $m^{-3}$) was lower in range than from a previous survey, which recorded 0.02 to 7.8 inds. $m^{-3}$ (Froneman et al., 1998; Froneman and Pakhomov, 1998; Pakhomov et al., 2000; Giesecke et al., 2010). In the present study, low abundance of *S. gazellae* was found south of the SB-ACC during the four months. This tendency concurs with previous reports. Their abundance has been reported as low between 65°S and the ice shelf, and to increase going northwards (David, 1955; Terazaki, 1989; Giesecke et al., 2010).

Few *S. marri* were caught during this study. They have a vertical distribution mainly associated with warm deep waters, and are almost absent at the surface (David, 1958, 1965; Johnson and Terazaki, 2004; Kruse et al., 2009; Giesecke and González, 2012). Indeed, Johnson and Terazaki (2004) recognized high concentrations at 300–500 m depth at Station 16 (64°40′S) in January 2002. Meso- and bathypelagic species like *S. maxima*, *S. macrocephala*, *E. bathyantarctica*, *E. bathypelagica* and *Heterokrohnia mirabilis* were not collected in this study because of our shallow sampling depth (0–150 m) in the epipelagic layer.

### 4.3. Comparison of primary production and abundance of copepods and chaetognaths

According to Øresland (1990), Copepoda were a major food source of *E. hamata* in the Gerlache Strait, Antarctica, with *E. hamata* consuming between 5 and 11% of its own dry weight in copepods per day. Large copepods are more important than small copepods as food for *E. hamata*; they consumed *Rhincalanus gigas*, *Calanoides acutus* and *Calanus simillimus* in the 1983/84 summer (Terazaki, 1989). However, these dominant large copepods are usually more abundant north of the SB-ACC and decrease toward the continent in our survey line (Hosie et al., 2000; Tanimura et al., 2008). The remarkable difference in *E. hamata* abundance between north and south of the SB-ACC was mainly due to the disappearance of *C. acutus* and *Calanus propinquus* in the south (Tanimura et al., 2008). Copepod distribution, as well as hydrographic conditions, might be important factors that determine seasonal distribution of *E. hamata* in this region.

The importance of ice edge dynamics in relation to primary production in polar regions has been established (Brierley and Thomas, 2002). It has been estimated that ice edge blooms have a productivity of 4–8 times that of open waters (Smith and Nelson, 1986). The fact that the abundance of copepods in the southern area near the ice edge was low despite high primary production, suggests that favorable food link conditions among phytoplankton/herbivorous copepods/chaetognaths may not have been functioning in this region. More data must be collected by future studies to explain this phenomenon.

The comparison of chaetognath abundances between the present findings and those of the 1983 and 1994 reports indicate a large difference between 1983 and other years (Table 2). Chaetognaths were particularly common in the 1927 Continuous Plankton Recorder (CPR) samples (Hardy, 1936), and their changes in abundance corresponded with changes in the abundance of large copepods in those tows. Modern CPR samples are dominated by small calanoid and cyclopoid copepods, and there is a general paucity of chaetognaths (Hosie et al., 2003; Takahashi et al., 2010). There has been a statistically significant decrease in abundance of dominant pelagic copepods in the Southern Ocean between the *Discovery* investigations (1929–1939) and modern investigations (1983–1993) (Kawamura, 1986; Vuorinen et al., 1997). These results also suggest that possible changes have occurred in the abundance and relative compositions of the macrozooplankton community of the Southern Ocean. One possibility causing the reduction of chaetognath abundance might be the lack of large herbivorous copepods during 20 years following 1983.

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